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Bulletin No. 120 - The Chemical Composition of Crops as Affected by Different Quantities of Irrigation Water

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Utah Agricultural College

EXPERIMENT STATION

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The Chemical Composition of Crops as Affected by Different Quantities of Irrigation Water

BY

JOHN A. WIDTSOE and ROBERT STEWART

In Co-operation with the Irrigation Investigations, Office of Experiment Stations, U. S. Department of Agriculture

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The Chemical Composition of Crops as Affected by Different Quantities of Irrigation Water

by

John A. Widtsoe and Robert Stewart.

I. INTRODUCTION.

In earlier bulletins it has been shown that when the quantity of irrigation water applied to crops is varied, the yields of the total crop as well as of the several plant parts vary quite definitely. The readiness with which plants respond to differences in irrigation is really remarkable and undoubtedly lies at the foundation of the future science of irrigation.

Variations in the quantities of irrigation water not only affect the total yield of dry matter, but also the composition of the plant itself. This fact was brought out many years ago in the investigations of this Station.*

Of the crops raised with different quantities of water, in all the later irrigation investigations, samples were frequently taken and subjected to chemical analyses. The data, thus obtained, have been collected, averaged and presented for consideration in the present bulletin.

In the past, we have valued a crop almost entirely by its weight. One bushel of wheat is as good as another providing they look nearly alike and weigh 60 pounds each. So

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*See Utah Station Bulletin No. 80.

with potatoes and other crops. With increasing knowledge the mere weight valuation of crops becomes of less consequence; we are learning rapidly that the quality of crops may be quite as important as the quantity in determining their value for the use of man or beast. The time is undoubtedly upon us when quality valuations will be given greater importance than ever before. A number of agricultural industries already make significant use of quality valuations in their work. For instance, the sugar beet factories purchase beets not only by the ton, but also upon the basis of their sugar content. In every case the contracts with the farmers specify a certain price per ton with a specified minimum percentage of sugar. Potatoes and other crops, likewise, are gradually being valued according to composition as well as to actual weight.

This trend is becoming stronger as the popularization of knowledge concerning food and its relation to the animal body increases. As a result there will, doubtless, be an increasing demand for foods of definite composition. The growth of this spirit among the people will be felt by the world markets; then the irrigation farmer will be at a decided advantage for he will be able to regulate, within rather wide limits, the composition of his crops. It is upon such refinements that the regions devoted to irrigation agriculture will be able to compete with all other sections of the world. The crops that can be grown properly under irrigation must be so developed that their quality shall be superior to that of similar crops grown elsewhere.

II. METHODS.

The crops used in this investigation were all obtained in the regular irrigation experiments, reported in several recent bulletins of this Station.* They were grown on the Greenville Farm of the Utah Experiment Station, which was provided with a system of weirs and flumes, permitting the application of accurately measured quantities of water to any

*See Utah Station Bulletins Nos. 115 to 120, inclusive.

plat. Unfortunately, complete sets of samples were not taken every year, therefore, the average results herein presented do not correspond closely with the yields obtained over long periods of years as recorded in the bulletins above mentioned. Enough samples were taken, however, to make the results herein presented thoroughly compatible with the truth.

The soil of the Greenville Farm is very fertile, very deep and uniform throughout. The annual rainfall is about 15 inches. Every known method was used to store in the soil the largest possible quantity of the natural precipitation; consequently, at seeding time of the following year, the soil was plentifully supplied with moisture. When this moisture was appreciably exhausted, irrigation commenced. No crop really suffered for want of water. Most of them received all the water necessary for maturing; more being applied in many cases, than could be used to the best advantage. These facts must be kept in mind in considering the results that follow.

The variations in composition are not so great as those that were obtained some years ago on the College Farm, which has shallower and poorer soils.* This is only to be expected because of the smaller percentage differences in the total water content of the deep Greenville Farm soils. When much water was applied to these soils, it distributed itself, with regularity, to considerable depths; when little was applied, it distributed itself with equal regularity, but to shallower depths, consequently the moisture environment in these soils was not greatly different at any one time.

The results recorded here may be looked upon as minimum in their variations. In almost every soil of the arid west, on which irrigation is practiced, greater variations will be found, owing to the varying methods of irrigation. Since the results here obtained are not maximum in their nature, the conclusions based upon them are perhaps quite within the limit of certainty.

The crops were analyzed according to the methods of the Association of Official Agricultural Chemists. To any per-

*See Utah Station Bulletin No. 80.

son familiar with the subject, it will be clear that an exhaustive study was not made into the composition of any of the crops. The data herein presented deal with general results and conditions; but, even as they are, the results are suggestive and may lead other investigators into a more detailed study of the composition of crops grown with different quantities of irrigation water. To him who aids in the founding of the science of irrigation, this is a great untrodden field than which there is none worthier.

III. THE PERCENTAGE OF WATER.

The water content was determined in all samples taken of crops as harvested. The effect of different quantities of irrigation water upon the per cent of water found in growing crops has been discussed briefly in Bulletin No. 119. In Table No. 1, are found some of the results obtained from the kernels and from the straw of wheat, oats and barley and from hay produced from several other plants. In the kernels of wheat, oats, barley and corn, the per cent of moisture increased slightly as the quantity of irrigation water increased. In the straw of these crops there was no regular correlation of the moisture content and the quantity of irrigation water. In each of the alfalfa crops, the percentage of water varied considerably, appearing to bear no definite relationship to the quantity of irrigation water used. Likewise, in the hay obtained from timothy, bromus inermis, and Italian rye grass, there was no general variation that could be ascribed to differences in amounts of water. These results should probably have been expected; for the straw of the grains as well as the hays just mentioned, were all exposed to the air and sunshine for considerable periods of time before they were finally analyzed. Whatever changes may be effected by varying the quantity of irrigation water are not such as to affect the water content in the face of the curing process in an arid climate. It is of great interest, however, to know that the kernels of the grains contained more water when they were grown with larger quantities of water. This can be explained upon the basis that all crops, during growth, tend

TABLE NO. 1.

THE EFFECT OF DIFFERENT QUANTITIES OF IRRIGATION WATER ON THE PER CENT OF WATER IN CROPS, AS HARVESTED.

Depth of Irrigation Water Used (Inches)	Wheat Kernels	Oats Kernels	Barley Kernels	Corn Kernels	Wheat Straw	Oats Straw	Barley Straw	Alfalfa			Timothy	Bromus Inermis	Italian Rye Grass	
								1st Crop	2nd Crop	3rd Crop			1st Crop	2nd Crop
5.0	6.89	4.93	----	----	4.24	3.07	----	----	----	----	----	----	----	----
7.5	7.37	----	6.88	----	4.39	----	4.81	----	----	----	8.49	17.65	11.46	9.37
10.0	7.41	5.73	----	4.79	4.91	3.37	----	7.20	14.40	14.27	----	17.25	----	----
15.0	7.38	5.63	8.13	5.83	4.19	3.37	4.18	10.47	23.22	13.53	10.36	17.63	16.24	14.73
20.0	----	5.51	----	----	----	3.37	----	9.97	11.80	10.46	----	----	----	----
25.0	7.99	----	----	5.57	4.42	----	----	6.45	12.52	9.92	----	----	----	----
30.0	----	----	----	5.97	----	----	----	6.93	12.72	10.49	11.04	----	----	----
35.0	----	----	----	----	4.55	----	----	----	----	----	----	----	----	----
40.0	----	----	8.33	----	----	----	4.93	----	----	----	----	16.85	----	----
45.0	----	6.18	----	----	----	3.83	----	----	----	----	----	----	15.25	10.93
50.0	8.99	----	----	----	----	----	----	8.32	13.17	9.92	----	----	----	----
55.0	----	----	----	5.89	----	----	----	----	----	----	----	----	----	----
60.0	----	----	----	----	----	----	----	----	----	----	9.78	----	----	----
65.0	----	----	----	----	----	----	----	----	----	----	----	----	----	----
100.0	----	----	----	----	----	----	----	----	----	----	10.25	18.80	13.34	10.58

to appropriate more water as the per cent of moisture in the soil rises. The kernels are so protected that, even between harvest and threshing time, they do not dry out so completely as do straw and hay, and so the variation that originally existed is still evident.

On a number of occasions, tests were made to determine whether there is a definite relationship between the per cent of moisture in the plant and that in the soil. In a field of wheat, for instance, determinations were made daily, for long periods, of the per cent of moisture contained in the growing plant and also in the soil. It seemed, invariably, to be the case, that as the per cent of moisture in the soil increased the per cent in the growing plant was also increased. When, however, the plant is cured by exposure to the sunshine and the air, the amount of moisture remaining in the crop depends entirely upon the drying process, especially upon the length of the curing period and upon the weather conditions.

IV. THE PERCENTAGE OF ASH.

The ash was obtained by careful combustion in open crucibles, a method not possessing the highest reliability. Some concordance, however, is found among the results obtained. Table No. 2, gives the average per cents of ash in the crops studied.

The kernels of wheat, oats, barley and corn, all showed an increase in their ash content as the quantity of water was increased above the smallest irrigation. From the smallest application on, the per cent of ash rose rather steadily; when the maximum quantity was used, this component remained either practically constant or fell slightly. With the various amounts of water the ash in the straw of these crops fluctuated in a manner similar to that in the kernels.

Alfalfa, timothy, bromus inermis, orchard grass and Italian rye grass all showed the same tendency. The more water that was applied, the higher was the per cent of ash in the crop, except, possibly in the case of the very largest irrigations. For the sub-aerial parts of the grain and fodder crops,

TABLE NO. 2.

THE PER CENT OF ASH IN CROPS.

(Referred to Dry Matter)

Depth of Irrigation (Inches)	Wheat Kernels	Oat Kernels	Barley Kernels	Corn Kernels	Wheat Straw	Oat Straw	Barley Straw	Corn Stover	Alfalfa. First Crop	Alfalfa. Second Crop	Alfalfa. Third Crop	Timothy	Bromus Inermis	Orchard Grass	Italian Rye Grass First Crop	Italian Rye Grass Second Crop	Sugar Beets	Carrots	Potatoes	Cabbage	Onions
3.75																		6.52			
5.00	2.57	4.56			8.85	9.95								9.02			4.03		4.32		
7.50	2.02		2.54	2.07	10.08		13.88	8.64				5.34	7.10		8.97	7.46		7.24			
10.00		4.53		1.61	9.74	12.19		7.56			8.16		7.43	8.69			3.52		4.16	6.44	
15.00	2.05	4.52	2.59	1.52	10.69		14.87	7.97			8.44	5.92		9.14	7.47	7.97	3.34	6.56	4.64		3.76
20.00		4.31		2.20		12.18		8.54	7.48	8.62	8.35						4.83		4.35	8.31	3.75
25.00	2.44		2.42		11.11		14.81	9.12	8.62	8.58	8.15							6.43		8.41	
30.00								9.15	8.37	8.56								7.26			
35.00	2.75				13.54						8.79	5.66					6.20		4.22		3.71
40.00			2.73				14.88						8.38	9.30							
45.00		5.34				11.55									9.09	8.59			3.88		
50.00	2.59				11.11				12.28	9.16	8.53						3.33				
55.00								10.66													
60.00												5.99		11.37				6.52			
65.00																					3.75
100.00												7.42	7.73			10.10					

these results are in full accord with those obtained in the study of the effects of different quantities of water upon the composition of crops at different periods of their development.

The ash of plants is a measure of the foods taken from the soil by the plant. The more water that is used in irrigation, the more plant food apparently is required to produce a unit of dry matter. The ash itself has not been analyzed for its different constituents, but it is not at all unlikely that, when such detailed examination is made, it will be found that as more water is applied to crops the cost of plant food per unit of dry matter produced is also greater. Since, in an irrigated as well as in a humid region, the fertility of soils is of fundamental importance, this increase in the per cent of ash is the strongest argument yet found against the excessive use of water. The farmer who uses a small amount of water per acre in the production of his crops not only obtains a larger yield of dry matter per unit of water used, but he also uses a smaller quantity of plant food for each unit of dry matter obtained. This needs to be considered in the establishment of a permanent system of agriculture under irrigation.

The root crops—sugar beets and carrots—also showed an increased percentage of ash as the quantity of irrigation water increased. However, for most of these crops it seemed to be quite evident that with the smaller quantities of water used, up to 75 inches, there was a larger percentage of ash, which diminished as more water was applied, and then increased as larger quantities were again used.

The per cent of ash in the potato crop remained practically constant with any quantity of water used. It will be remembered that potato tubers have always shown some deviation from ordinary results.

In cabbage the per cent of ash increased rather rapidly as the amount of water was raised from 12.5 to 25 inches. With onions, however, the percentage remained practically the same as the quantity of water used was increased from 15 to 65 inches.

Taking these results all in all, it may be safely said that the seeds and stalks of plants accumulate more ash materials as more water is used in their production; that root crops obey the same law, as does also cabbage, but onions and potatoes do not show the same marked variation in this direction, though in all probability more exact investigations will show that the law applies even there. Considering the plant as a whole, there is undoubtedly an increase in the per cent of ash as the quantity of irrigation water is increased.

It may be repeated that this is a subject of fundamental importance since it concerns itself with the fertility of our irrigated soils. The waste that occurs by using large quantities of water is twofold; it diminishes the yield of dry matter per unit of water used, and it increases the soil fertility cost per unit of dry matter produced. A promising investigation would be the examination of the ash from the plants grown with different quantities of water to determine what substances are taken up in largest ratio as more irrigation water is applied.

V. THE PERCENTAGE OF PROTEIN.

The plant constituents that contain nitrogen are of greatest importance in the maintenance of animal life. When organized into proteid forms, these nitrogenous substances form the basis for the production of blood, muscles and all other tissue of the animal body. In fact, for the purposes of animal feeding, the value of a crop may be well measured by its per cent of nitrogenous material.

Protein is a term applied to all the plant substances, containing nitrogen. These compounds are not all of equal value. Some are burned to furnish body heat, merely, while others enter into the very structure of the body. As in the case of the ash, no detailed examination was made of the protein of crops grown with different amounts of water, though it is a most alluring field for research. In Table No. 3 are shown the per cents of protein obtained in the various crops grown in these experiments.

TABLE NO. 3.

THE PER CENT OF PROTEIN IN CROPS.

(Referred to Dry Matter)

Depth of Irrigation (Inches)	Wheat Kernels	Oat Kernels	Barley Kernels	Corn Kernels	Wheat Straw	Oat Straw	Barley Straw	Corn Stover	Alfalfa First Crop	Alfalfa Second Crop	Alfalfa Third Crop	Timothy	Bromus Inermis	Orchard Grass	Italian Rye Grass First Crop	Italian Rye Grass Second Crop	Sugar Beets	Carrots	Potatoes	Cabbage	Onions
3.75	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	8.81	......	......	......
5.00	18.05	19.74	......	......	5.36	4.88	......	......	......	......	......	......	......	9.51	......	......	5.71	......	11.19	......	......
7.50	17.07	......	15.53	12.86	5.69	......	4.84	5.68	......	......	......	7.06	10.70	......	9.61	8.90	......	8.76	......	......	......
10.00	16.91	18.80	......	12.70	5.58	6.30	......	6.70	16.32	15.49	17.94	......	9.82	9.72	......	......	5.27	......	11.05	......	......
15.00	16.45	18.81	14.63	12.64	5.28	5.19	4.47	5.69	16.11	16.47	17.36	7.63	9.81	9.39	9.67	8.28	5.47	8.78	11.87	......	9.74
20.00	......	18.65	......	......	......	5.29	......	6.39	16.54	16.54	17.22	......	......	......	......	......	6.09	......	9.95	22.23	10.08
25.00	16.22	......	13.82	12.26	5.25	......	4.40	5.75	16.18	16.44	17.44	......	......	......	......	......	......	8.45	......	23.12	......
30.00	......	......	......	12.18	......	......	......	4.88	16 03	16.64	16.72	7.21	......	......	......	......	6.54	......	10.08	......	9.77
35.00	15.89	......	......	......	5.01	......	......	......	......	......	......	......	......	......	......	......	......	8.26	......	......	......
40.00	......	......	14.23	......	......	......	4.80	......	......	......	......	......	9.87	8.73	......	......	......	......	......	21.32	......
45.00	......	17.81	......	......	......	......	......	......	......	......	......	......	......	......	9.12	8.37	......	......	8.71	......	......
50.00	15.98	......	......	......	5.77	......	......	......	16.69	17.71	16.50	......	......	......	......	......	4.92	......	......	......	......
55.00	......	......	......	12.10	......	......	......	4.62	......	......	......	......	......	......	......	......	......	......	......	......	......
60.00	......	......	......	......	......	......	......	......	......	......	......	8.00	......	8.71	......	......	......	7.88	......	......	......
65.00	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	12.05
100.00	......	......	......	......	......	......	......	......	......	......	......	7.34	9.31	......	10.59	7.62	......	......	......	......	......

Even a casual examination of the results obtained with the seeds of wheat, oats, barley and corn, shows that the law already stated by this Station many years ago holds good for the crops grown on the Greenville Farm. The smaller the quantity of water used in irrigation the larger the percentage of protein. In wheat kernels, the diminution was from 18 to 16 per cent, or over one ninth; in oat kernels about the same diminution; in barley kernels a little less, and in corn kernels yet a smaller decrease was observed. In every case, however, the per cents of protein diminished as the quantities of irrigation water increased.

This variation is not so marked when the straw of the grain crops is examined. The per cent of protein in wheat straw remained practically constant; with oat straw there seemed to be a slight increase in protein as the water increased; with barley straw there was a practical constancy; with corn stover the tendency was downward as the quantity of water increased. In a more detailed investigation it has been shown that the per cent of protein in the straw of the grains really does diminish as the quantity of irrigation water increases. It must also be recalled that the accurate sampling of straw is much more difficult than it is with grain.

The fodder crops—alfalfa, timothy, bromus inermis, orchard grass and Italian rye grass—showed that the per cent of protein decreases somewhat as the quantity of irrigation water increases. The first crop of lucern, which depends almost entirely upon the natural precipitation, shows, as would be expected, practically no variation. The second crop, rather unexpectedly, showed an increase of protein as the water increased. This may be due to the fact that during the season when the second crop grows, nitrification goes on most rapidly and so the crop is enabled to obtain the nitrates very readily from the soil or the free nitrogen from the air. The third crop, however, showed a rather distinct decrease in the per cent of protein as the quantity of irrigation water increased. The per cent of protein in timothy remained practically constant under varying conditions of irrigation; in bromus inermis and in orchard grass the protein decreased as the water increased; but in the first crop of Italian rye grass, it remained practically the same; while in the second crop there was a distinct diminution with the increase in water. A great variation is not to be expected in any of these crops, excepting those that yield two or more cuttings, because they are harvested rather early in the season and depend largely, for their dry matter, upon the natural precipitation stored in the soil. There would, as a consequence, be smaller differences as an effect of irrigation than in the case of crops that are harvested later. Clearly, however, the law holds with the fodder crops that the per cent of protein tends to decrease as the quantity of irrigation water increases.

The root crops—sugar beets **and** carrots—did not show a marked variation in the per cent of protein, as a result of varying quantities of irrigation water. The per cent of protein in the former seemed to increase as the irrigation water was increased up to 30 inches; beyond this point, the protein diminished. In carrots the nitrogen compounds seemed to decrease steadily and regularly, as the quantity of irrigation water increased. Similarly, with potatoes there was a distinct decrease in the per cent of protein with an increase of water. These three crops all obey the general law as above stated. The apparent failure of sugar beets to conform to this order of variation with the smaller quantities of water cannot be explained, though experimental error may be suggested.

The protein in cabbage decreased slightly as the quantity of water increased. In onions it rather tended to increase as the water was increased.

It is probably very difficult to lay down general laws for plants and their several parts regarding the protein percentage. It may be safe to say, however, that the percentage of protein in the above-ground parts of plants varies inversely with the quantity of water applied, especially is this true of the seeds. The roots, under normal conditions, obey the same law, their protein content being highest when the quantity of water applied is smallest. In poorer or shallower or less uniform soils than those of the Greenville Farm, this regular variation in the protein content would be much more marked.

VI. THE PERCENTAGE OF ETHER EXTRACT.

In Table No. 4 are arranged the average per cents of ether extract in the various crops, each grown with different quantities of irrigation water. The variation is so irregular that no deduction of any importance can be made. The data are submitted merely as a matter of record. When one considers the complex nature of the ether extract, it would not have been a little surprising if any intelligible results had been obtained. A more detailed study of the ether extract, including the identification of its simpler constituents, should make a difficult though fruitful field for effort.

VII. THE PERCENTAGE OF CRUDE FIBER.

The crude fibre refers to that portion of the plant which is not made soluble by the successive use of strong acids and alkalies. It may not be of much significance with regard to the nutrition of animals, but it does furnish an index to the woodiness of crops. For that reason it has been included in this investigation. Table No. 5 presents the data obtained. In the seeds of wheat, oats, barley and corn the percentage of crude fiber remains practically constant as the quantities of irrigation water increase. In the straw of these crops, however, the percentage of crude fiber increases rather regularly and strongly as the quantity of irrigation water increases. The stalks and leaves of crops grown with much water are more woody than those grown with smaller amounts.

This general tendency is also very marked in the fodder crops—timothy, bromus inermis, orchard grass and two crops of Italian rye grass. In every instance, there is an increase in crude fiber as the amount of water used increases. It is to be noted, however, that the largest increase comes only after excessive applications of water, those that are far too high for the best plant production. Within reasonable

TABLE NO. 4.

THE PER CENT OF FAT (ETHER EXTRACT) IN CROPS.

Depth of Irrigation (Inches)	Wheat Kernels	Oat Kernels	Barley Kernels	Corn Kernels	Wheat Straw	Oat Straw	Barley Straw	Corn Stover	Alfalfa			Timothy	Bromus Inermis	Orchard Grass	Italian Rye Grass		Sugar Beets	Carrots	Potatoes	Cabbage	Onions
									First Crop	Second Crop	Third Crop				First Crop	Second Crop					
3.75	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	1.21	......	......	......
5.00	2.38	5.41	......	......	2.26	......	......	......	......	......	......	......	......	3.58	......	......	1.03	......	......	......	......
7.50	2.19	......	1.40	6.22	1.95	......	2.59	......	......	......	......	2.89	3.29	......	3.55	3.53	......	1.81	......	......	......
10.00	2.42	4.79	......	6.73	2.27	......	......	......	......	......	......	......	3.51	3.88	......	......	.51	......	......	......	......
15.00	2.57	5.46	2.23	6.17	1.72	......	3.20	1.40	......	......	......	2.88	3.95	4.19	3.36	3.50	.54	1.54	......	......	......
20.00	......	4.42	......	6.09	......	......	......	1.54	......	......	......	......	......	......	......	......	.57	......	.86	2.06	2.01
25.00	2.50	......	2.57	6.18	1.69	......	2.48	1.68	......	......	......	......	......	......	......	......	......	1.63	......	1.95	......
30.00	......	......	......	6.03	......	......	......	1.12	......	......	......	2.58	......	......	......	......	.49	......	.54	......	1.33
35.00	2.25	......	......	......	1.83	......	......	......	......	......	......	......	......	......	......	......	......	1.71	......	......	......
40.00	......	......	2.06	......	......	......	2.66	......	......	......	......	......	3.92	3.72	......	......	......	......	......	1.50	......
45.00	......	4.47	......	......	......	......	......	......	......	......	......	......	......	......	2.54	3.48	......	......	.55	......	......
50.00	2.54	......	......	......	1.64	......	......	......	......	......	......	......	......	......	......	......	.47	......	......	......	......
55.00	......	......	......	5.33	......	......	......	1.05	......	......	......	......	......	......	......	......	......	......	......	......	......
60.00	......	......	......	......	......	......	......	......	......	......	......	2.85	......	4.21	......	......	......	1.95	.44	......	......
65.00	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	1.36
100.00	......	......	......	......	......	......	......	......	......	......	......	3.23	3.83	......	2.42	4.35	......	......	......	......	......

TABLE NO. 5.

THE PER CENT OF CRUDE FIBER IN CROPS.

(Referred to Dry Matter)

Depth of Irrigation (Inches)	Wheat Kernels	Oat Kernels	Barley Kernels	Corn Kernels	Wheat Straw	Oat Straw	Barley Straw	Corn Stover	Alfalfa.			Timothy	Bromus Inermis	Orchard Grass	Italian Rye Grass		Sugar Beets	Carrots	Potatoes	Cabbage	Onions
									First Crop	Second Crop	Third Crop				First Crop	Second Crop					
3.75	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	8.51	......	......	......
5.00	3.09	11.54	......	......	35.65	......	......	......	......	......	......	......	......	29.96	......	......	6.47	......	......	......	......
7.50	2.98	......	4.58	1.99	36.31	......	33.91	......	......	......	......	26.03	31.36	......	27.31	29.85	......	7.93	......	......	......
10.00	2.86	11.17	......	1.81	35.18	......	......	......	......	......	......	......	32.34	30.75	......	......	5.26	......	......	......	......
15.00	2.82	11.05	3.14	1.85	35.19	......	32.54	33.26	......	......	......	26.97	32.13	31.50	26.14	29.61	4.89	6.68	......	......	......
20.00	......	11.22	......	2.04	......	......	......	33.98	......	......	......	......	......	......	......	......	4.52	......	2.55	13.55	......
25.00	2.58	......	4.70	1.92	35.64	......	34.13	33.64	......	......	......	......	......	......	......	......	......	8 32	......	13.76	......
30.00	......	......	......	1.87	......	......	......	34.80	......	......	......	32.17	......	......	......	......	5.23	......	2.65	......	7.02
35.00	2.58	......	......	......	35.49	......	......	......	......	......	......	......	......	......	......	......	......	9.96	......	......	......
40.00	......	......	4.83	......	......	......	36.20	......	......	......	......	......	32.10	33.09	......	......	......	......	......	14.60	......
45.00	......	9.84	......	......	......	......	......	......	......	......	......	......	......	......	26.12	31.39	......	......	3.29	......	......
50.00	2.86	......	......	......	38.26	......	......	......	......	......	......	......	......	......	......	......	4.80	......	......	......	......
55 00	......	......	......	2.17	......	......	......	35.10	......	......	......	......	......	......	......	......	......	......	......	......	......
60.00	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	8.28	2.14	......	......
65.00	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	7.00
100.00	......	......	......	......	......	......	......	......	......	......	......	......	34.40	......	26.47	35.11	......	......	......	......	......

limits of irrigation the change in the per cent of crude fibre is not great.

This variation of crude fibre does not seem to obtain, however, for root crops. Both in sugar beets and in carrots the changes in the crude fiber content with the different quantities of water applied are not regular, being in most cases easily within experimental error. The same may be said of potatoes, cabbage and onions.

As a general conclusion then, it may be said, that the above-ground parts of plants, with the exception of the seeds and some specialized parts, such as cabbage heads, and onion bulbs, tend to become more woody as more water is used; but, that the under-ground parts are not influenced largely in their crude fiber content by the quantity of water used in irrigation. Undoubtedly, there is the possibility of increasing the crude fiber content by an excessive use of irrigation water. Small increases of crude fiber do not necessarily exert a deleterious influence upon the quality of crops; but it is desirable that it should be kept as low as possible.

VIII. THE TOTAL YIELD OF ASH PER ACRE.

In Table No. 6 will be found the actual acre weights of ash in the crops grown with different quantities of water. These were obtained, in every case, by multiplying the total yields of dry matter as given in Bulletin No. 116 by the average per cents of ash as given in Table No. 2 of this bulletin. Since the analyses do not cover all the years represented by the dry matter averages, the results cannot be expected to possess the highest degree of accuracy, yet they should come within reasonable limits of truth.

Considering first the sum of the kernels and straw of wheat, oats, barley and corn, it may be noticed that there is a steady and large increase in the total yield of ash per acre as the quantity of irrigation water increases. This is only to be expected, in view of the fact that the per cent of ash as well as the total yield of dry matter increases as irrigation increases.

TABLE NO. 6.

THE TOTAL YIELD OF ASH IN CROPS.

(Pounds per acre)

Depth of Irrigation (Inches)	Wheat Kernels	Oat Kernels	Barley Kernels	Corn Kernels	Wheat Straw	Oat Straw	Barley Straw	Corn Stover	Alfalfa.			Timothy	Bromus Inermis	Orchard Grass	Italian Rye Grass		Sugar Beets	Carrots	Potatoes	Cabbage	Onions
									First Crop	Second Crop	Third Crop				First Crop	Second Crop					
3.75																		490			
5.00	57	164			244	189								201			245		100		
7.50	48		98	115	318		519	449				210	283		159			523			
10.00		138		99	316	251		502			168		302	187			283		122		
15.00	53	176	98	95	397		633	543			122	221		197	132		288	657	158		81
20.00		200		149		349		607	259	253	165						487		174		
25.00	63		90		455		618	676	301	256	174							676			
30.00								790	256	263	176	313					637		154		120
35.00	75				612													848			
40.00			92				812						329	301							
45.00		244				388									137				147		
50.00	68				597				429	338	236										
55.00								717													
60.00												420		392				970			
65.00																					128
100.00													227								

The same is true in general, with either the kernels or the straws of these crops, though it may be noticed, as perhaps the most striking feature of this investigation, that the total yield of ash in the kernels does not increase greatly as irrigation water is increased. In the straw, on the other hand, there is a very large and rapid increase of the yield of ash as the quantity of water increases. That is to say, the waste of soil fertility, due to excessive use of water falls chiefly on the straw, the least valuable part of the crop.

The fodder crops, likewise, showed, in general, an increase in the total weight of ash as the quantity of irrigation water increased. There was, however, a number of irregularities. In sugar beets, carrots, potatoes and onions, the total yield of ash increased steadily and somewhat rapidly as the quantity of irrigation water was increased.

Table No. 6 teaches, all in all, that the total yield of ash per acre, whether for the whole plant or for any of the above-ground parts, or for the roots, increases steadily as the quantity of irrigation water increases.

IX. THE TOTAL YIELD OF PROTEIN PER ACRE.

In Table No. 7, the total yields of protein have been determined in the same way as the total yields of ash were determined in the preceding table.

Considering first the sum of the protein in the kernels and in the straw of wheat, oats, barley and corn, it will be observed that the total yield of protein in wheat increased, though very slightly, for every increase in the quantity of water applied. With oats there was no increase from 5 to 15 inches, and only a slight rise when 20 inches was employed; in barley, the highest yield of protein came with 7.5 inches, but became smaller with increased amounts; in corn, it was practically constant throughout. This shows that for the above-ground parts of the grains, the increase in the total yield of protein per acre, as the quantity of irrigation water is increased, is very small, and approaches constancy.

TABLE NO. 7.

TOTAL YIELD OF PROTEIN PER ACRE.

(Pounds per Acre.)

Depth of Irrigation (Inches)	Wheat Kernels	Oat Kernels	Barley Kernels	Corn Kernels	Wheat Straw	Oat Straw	Barley Straw	Corn **Stover**	Alfalfa. First Crop	Alfalfa. Second Crop	Alfalfa. Third Crop	Timothy	Bromus Inermis	Orchard Grass	Italian Rye Grass First Crop	Italian Rye Grass Second Crop	Sugar Beets	Carrots	Potatoes	Cabbage	Onions
3.75	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	662	----	----	----
5.00	399	711	----	----	149	97	----	----	----	----	----	----	----	212	----	----	347	----	258	----	----
750	409	----	598	754	179	----	181	295	----	----	----	277	427	----	170	----	----	633	----	----	----
10.00	412	574	----	777	181	130	----	445	552	581	370	----	399	209	----	----	424	----	323	----	----
15.00	422	732	554	793	196	121	190	388	473	420	252	285	332	203	171	----	472	879	404	----	209
20.00	----	865	----	----	----	151	----	454	572	486	340	----	----	----	----	----	614	----	399	412	222
25.00	418	----	513	882	215	----	184	426	564	491	372	----	----	----	----	----	----	889	----	377	----
30.00	----	----	----	811	----	----	----	421	491	511	335	398	----	----	----	----	672	----	369	----	317
35.00	431	----	----	----	226	----	262	----	----	----	----	----	----	----	----	----	----	964	----	----	----
40.00	----	----	481	----	----	----	----	----	----	----	----	----	388	282	----	----	----	----	----	436	----
45.00	----	813	----	----	----	----	----	----	----	----	----	----	----	----	138	----	----	----	331	----	----
50.00	420	----	----	----	310	----	----	----	583	654	456	----	----	----	----	----	567	----	----	----	----
55.00	----	----	----	716	----	----	----	311	----	----	----	----	----	----	----	----	----	----	----	----	----
60.00	----	----	----	----	----	----	----	----	----	----	----	----	----	300	----	----	----	732	----	----	----
65.00	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	412
100.00	----	----	----	----	----	----	----	----	----	----	----	----	274	----	----	----	----	----	----	----	----

When the kernels are examined, it is found that in the case of wheat under different quantities of water, the yield of protein remains practically constant; with oats there was a small increase; in barley a slight decrease; and in the corn crop there was first a slight increase, up to about 30 inches, then a slight falling off. Evidently, the increasing yields of grain crops caused by increasing the quantity of irrigation water are not accompanied by corresponding increase in the total protein. Since this is the most important constituent of the seed of the cereals, it becomes of great importance to know the effect of irrigation upon it.

The straw of these crops increased slightly, in the total yield of protein as the quantity of water increased. But since straw has small value compared with the seed there is no great advantage in this increased protein yield.

Alfalfa, likewise, showed for each crop a remarkable constancy in the amount of protein per acre. So, also, did timothy, though as the water was increased, the protein increased quite rapidly. The other fodder crops remained either almost constant in their production of protein, or the total amount decreased as the water was increased.

The total yield of protein in the root crops—sugar beets and carrots—increased appreciably and steadily as the quantity of irrigation water increased; in potatoes there was a slight increase; in cabbage and especially in onions, the total amount of protein per acre increased as the amount of water increased.

In all crops the total acre-yield of protein tends to increase as the quantity of irrigation water increases; but in many crops, especially those of which the above-ground parts are harvested, the increase is so small as to be almost negligible. This essential plant constituent, protein, is not obtained in appreciably larger quantities by the application of large quantities of water. In fact, not only for the production of dry matter, but for the production of protein, smaller quantities of irrigation water are the most economical.

X. THE MAINTENANCE OF A HIGH PROTEIN PERCENTAGE.

The protein as previously mentioned is the most important plant constituent. The variations in composition, due to differences in the quantities of irrigation water applied, are greater with this part of the plant tissue than with any other, unless it be the crude fiber. It has been suggested that if a high protein content, say of wheat, induced by using small quantities of irrigation water, could be made to persist under more humid conditions, it might be possible for the irrigation sections to supply seed wheat to the districts where the rainfall is higher. This was rather a forlorn hope since the increased protein percentage is a characteristic acquired under the influence of varying quantities of water. The possibility seemed so inviting, however, that a small experiment on the subject was continued for a number of years.

A sample of New Zealand wheat, grown in 1902, was sown in 1903 on two plats, one of which received a small, the other a rather large quantity of water. As was expected, the wheats produced in 1903 on these plats differed in their protein content. In fact, the difference was more than four per cent. The low protein wheat thus obtained, (with about three inches of water) was grown in 1904 on two plats, one of which received a large quantity of water and the other a moderate amount; the high protein wheat was also grown on two plats, one of which received a small the other a moderate, quantity of water. This process was repeated the following year and similar work was done during the succeeding two years. In all, five generations were obtained from the original 1902 sample of New Zealand wheat. The results obtained are found in Table No. 8. While the data are not sufficient to permit of an extended generalization, it is fairly evident that the high percentage of protein induced by low quantities of irrigation water, does not persist in later generations when large quantities of water are used. In other words, a high protein content may be obtained at any time, no matter what the composition may have been the preceding year, by using

TABLE NO. 8.

THE PER CENT OF PROTEIN IN SUCCESSIVE GENERATIONS OF WHEAT.

% = Per Cent of Protein in Dry Matter.
In. = Inches of Irrigation Water.

NEW ZEALAND WHEAT.

1903	14.77% (41.9 in.)	18.84% (2.9 in.)		
1904	14.74% (46.5 in.)	16.71% (15.0 in.)	15.7 % (14.6 in.)	16.42% (3.8 in.)
1905	15.43% (38.1 in.)	16.63% (16.6 in.)	15.65% (17.0 in.)	17.74% (3.8 in.)
1906	14.11% (13.8 in.)	13.48% (17.7 in.)	13.74% (8.8 in.)	13.63% (15.6 in.)
1907	13.77% (35.0 in.)	14.02% (15.0 in.)	13.83% (13.3 in.)	13.69% (17.0 in.)

small quantities of water. Vice versa, a lower protein content will result by using large quantities of water. The subject is fascinating and may lead to some useful knowledge if more extended investigations should be undertaken concerning the ultimate effect of much or little water upon the composition of plants grown for successive generations.

XI. THE STARCH AND SUGAR IN POTATOES AND SUGAR BEETS.

Whenever potatoes or sugar beets are used by starch or by sugar factories, the per cent of starch in the former and of sugar in the latter assumes very high importance. It was thought desirable, therefore, to investigate briefly the variations in the per cents of starch and sugar in these crops, as it may be affected by the quantity of water used.

The first plan according to which this work was done was, as follows: samples of potatoes and of sugar beets, taken at harvest time, were rapidly and very carefully dried by artificial heat; the dry matter was then ground and later subjected to chemical analysis. The data of this work, in so far as it relates to the sugar and starch, are found in Table No. 9. Doubtless, in the process of drying, the starch and sugar underwent many changes. For that reason, too much reliance must not be placed upon the results. They are chiefly an indication of the direction which the variations are likely to take.

TABLE NO. 9.

THE PER CENT OF CARBOHYDRATES IN POTATOES AND SUGAR BEETS AS AFFECTED BY IRRIGATION.

(On Basis of Dry Matter.)

Depth of Irrigation Water Used (In.)	In Potatoes				In Sugar Beets			
	Reducing Sugars	Sucrose	Starch	Total	Reducing Sugars	Sucrose	Starch	Total
5	2.48	----	----	----	0.81	16.92	8.82	26.55
10	2.35	----	----	----	1.09	15.99	8.86	25.94
15	2.23	----	----	----	1.24	16.04	8.92	26.20
20	2.11	3.28	64.96	70.35	1.39	15.57	9.00	25.96
30	1.86	4.76	64.48	71.10	1.11	15.37	11.32	27.80
45	1.85	4.51	64.12	70.48	----	----	----	----
50	---	----	----	----	0.91	17.23	12.40	30.54
60	1.67	5.67	67.58	74.92	----	----	----	----

The first part of Table No 9 refers to potatoes for which reducing sugars, sucrose and starch were determined. As the quantity of irrigation water was increased the reducing sugars decreased regularly and steadily. On the contrary the sucrose increased liberally with the increase in the quantity of irrigation water. At first the starch appeared to remain somewhat constant, but with greater water applications it increased materially. Considering the sum of these three constituents in potatoes, there seems to be a slight though regular increase as the quantity of irrigation water is increased. When very large quantities of water are used the per cent of the carbo-hydrates is greatly increased.

Similar results were obtained with sugar beets. As the quantity of irrigation water was increased, the reducing sugars increased for a time, then finally decreased. The sucrose did not vary regularly, in fact, it was almost within experimental error, yet the tendency seems to be for the per cent of sugar to be highest when the quantity of water used is largest; although small amounts of water produced sweeter beets than did intermediate quantities. This matter is more fully set forth in Table No. 10. The per cent of starch in sugar beets increased as the total quantity of water was increased. When the sum of these carbo-hydrates is considered there appears clearly a tendency for the per cent of carbo-hydrates to increase as the total water increases. In general, therefore, sugar beets and potatoes behave alike so far as their per cents of carbo-hydrates are concerned. These conclusions are in full accord with the work done at this Station many years ago.*

It is noticeable, that by increasing the quantity of water the effect on the per cent of starch is greater than it is on that of the sugar. It is also interesting to know that the reducing sugars remain practically constant. In comparison with either the starch in potatoes or the sugar in beets, the per cent of reducing sugars is small. It is commonly believed that the latter are the active agents in building sucrose and starch, and, therefore, at any one time there should not be very large quantities of them in the plant.

Under the second plan of the experiment a number of beets were taken weekly from each plat of the irrigation experiments, from the first week in September, until harvest. These samples were immediately analyzed by the usual factory methods for the determination of sucrose and also the purity of the juice. At the time of harvest each plat of sugar beets was again sampled and analyzed. The data obtained from

*See Utah Station Bulletin No. 80.

this work are found in Table No. 10. The weekly samples covered two seasons; those made at the time of harvest, seven seasons.

The results obtained each week before harvest were averaged for September and October respectively, to show the composition of the beets during these months. These averages are shown in the first part of Table No. 10. As has been demonstrated in earlier investigations of this Station, sugar beets ripen, that is, become sweeter, as the end of the

TABLE NO. 10.

THE COMPOSITION OF SUGAR BEET JUICE.

Depth of Irrigation Water Used (In.)	Before Harvest. (Average of Two Years)				At Harvest. (Av. of 7 Years)	
	Per Cent Sucrose		Per Cent Purity		Per Cent Sucrose	Per Cent Purity
	September	October	September	October		
5.0	15.46	16.39	83.09	84.58	----	----
7.5	----	----	----	----	14.44	77.21
10.0	15.35	16.81	83.50	80.53	15.33	80.46
15.0	14.44	16.04	82.39	84.06	15.12	81.49
20.0	----	----	----	----	15.13	81.09
25.0	14.86	16.59	83.04	84.64	14.22	79.24
30.0	----	----	----	----	15.68	79.30
35.0	15.64	17.39	86.16	87.54	15.41	79.54

season approaches. Under every condition of irrigation practiced in these experiments, the beet juice contained more sugar in October than in September, and the difference was fairly large, averaging 1.5 per cent. With one exception, the purity, also, was higher in October than in September.

The per cent of sucrose was not affected greatly by irrigation. In September, the two smallest quantities of water produced beets containing between 15 and 16 per cent of sucrose; the two next largest amounts gave beets containing about three-fourths of one per cent less of sucrose. The largest irrigation again raised the content of sucrose only about one-fifth of one per cent over that obtained with the smallest quantity of water. In October, the per cent of sucrose remained between 16 and 17 regardless of the quantity of water used, except with the largest irrigation (35 inches) when there was one per cent more sucrose in the juice than when the smallest amount was employed. The purity also remained fairly constant in October, though the highest per cent occurred with the largest quantity of irrigation water.

The more important results are found in the second section of Table No. 10, dealing with the percents of sucrose and purity at the time of harvest. Seven years work has been incorporated into the averages, a fact which should give considerable reliability. The percents of sucrose obtained with different quantities of water are not widely different. The two lowest per cents were obtained when 7.5 and when 25.0 inches of irrigation water were used; the two highest per cents when 30 and when 35 inches of irrigation water were used. Clearly, there is a tendency for the per cent of sucrose to increase as more water is used, up to at least 35 inches, but the variation is very small and not even approximately in proportion to the differences in water applied. Beets receiving 50 inches of water in some years were analyzed, but in every case the per cent of sucrose fell with these excessive amounts.

At harvest, the per cent of purity was lowest with the smallest quantity of water used; it was largest with intermediate applications, up to 20 inches; and then fell again, slightly, when greater amounts were used.

All in all, the conclusion that may be drawn from the hundreds of tests averaged in Table No. 10 is, simply, that intermediate quantities of water give fully as good results as large quantities do in the production of sucrose and of purity in the juice of sugar beets.

XII. THE EFFECT OF CULTURAL METHODS.

It is quite clear from the data already presented in this bulletin that the chemical composition of crops is responsive to the quantity of irrigation water employed. The question arose early in these investigations as to the effect that various cultural methods would have upon the composition of the crops. A mass of data on this subject, is in possession of the Station, but so far as it has been examined, it is largely of a negative character.

A number of tests were made, also, in which the crops were subjected to various cultural methods. Apparently there was no difference in the effect upon the composition under these different treatments beyond a rather strong tendency of the non-cultivated crops to contain a slightly higher per cent of protein.

In this discussion a brief summary is given of some other findings obtained. For instance, in Table No. 11 is found the per cents of ash and protein in crops that were grown under conditions exactly the same, except that one was irrigated by

TABLE NO. 11.

THE PER CENTS OF ASH AND PROTEIN IN CROPS AS AFFECTED BY THE METHOD OF IRRIGATION.

Crop	Average Inches of Irrigation Water Used	Flooding	Furrowing
PER CENTS OF ASH.			
Corn kernels	36	1.39	1.28
Corn stover	25	7.56	8.55
Wheat kernels	17	1.59	1.55
Potatoes (tubers)	31	3.80	3.78
PER CENTS OF PROTEIN.			
Corn kernels	27	12.74	12.88
Corn stover	31	6.27	6.31
Wheat kernels	17	15.98	16.33
Wheat straw	17	4.79	4.15
Oat kernels	10	17.67	17.63
Oat straw	10	5.45	5.68
Potatoes (tubers)	30	10.42	9.92
Cabbage	30	21.51	22.16

flooding and the other by the furrowing method. The variations in those plant constituents are small and come easily within experimental errors. As far as these data are concerned we are probably safe in saying that the variation in plant composition resulting from differences in methods of irrigation is so small as to be of no practical value.

In Table No. 12, are shown the per cents of protein in the kernels and straw of wheat, produced with different amounts of seed, and different methods of planting. The data seem to show that the total amount of seed per acre does not affect

TABLE NO. 12.

THE PER CENT OF PROTEIN IN WHEAT GROWN WITH DIFFERENT AMOUNTS OF SEED AND SEEDED UNDER DIFFERENT METHODS.

	Kernels	Straw
Three pecks seed used	14.19	3.93
Four pecks seed used	13.92	3.87
Six pecks seed used	14.31	3.54
Every other feed tube stopped	14.09	3.86
All feed tubes open	14.31	3.45

the composition of the kernels—at least so far as protein is concerned. In the straw, however, protein decreased rather steadily, though slightly, as the amount of seed increased. The differences are small and, as far as these data go it is probably safe to say that the amount of seed used does not result in any practical difference in the composition of the crop.

In Table No. 13 are shown the per cents of protein in wheat and oats grown with the same amounts of water, under different methods of distribution. Wheat receiving only one irrigation of about 3.5 inches, contained a higher per cent of protein when the water was applied at the usual time of the first irrigation, rather early in the season, than when this one irrigation was applied later, at the time the heads are filling out. When 7.5 inches of water were used, the per cent of pro-

TABLE NO. 13.

THE PER CENT OF PROTEIN IN WHEAT AND OATS AS AFFECTED BY THE DISTRIBUTION OF IRRIGATION WATER.

Distribution of the Irrigation Water.	Per Cent Protein (On Basis of Dry Matter)
WHEAT (3.5 inches).	
At usual time	21.75
Later, when heads are filling out	18.84
WHEAT (7.5 inches).	
Two irrigations (5.0; 2.5)	17.81
Two irrigations (2.5; 5.0)	16.65
Two irrigations (3.75; 3.75)	16.21
WHEAT (10 inches).	
Two irrigations (7.5; 2.5)	17.17
Two irrigations (2.5; 7.5)	16.40
Two irrigations (5.0; 5.0)	16.01
Three irrigations (2.5; 5.0; 2.5)	16.17
Three irrigations (2.5; 2.5; 5.0)	15.98
WHEAT (10 inches).	
Two irrigations (7.5; 2.5)	17.40
Two irrigations (2.5; 7.5)	17.03
Two irrigations (5.0; 5.0)	16.62
Three irrigations (3.33; 3.33; 3.33)	16.92
WHEAT (15 inches).	
Two irrigations (7.5; 7.5)	17.23
Three irrigations (7.5; 3.75; 3.75)	15.58
Three irrigations (5.0; 5.0; 5.0)	15.46
OATS (15 inches).	
Two irrigations (7.5; 7.5)	18.04
Three irrigations (5.0; 5.0; 5.0)	18.78

tein was highest, when the smallest amount of water was applied early; smallest, when the water was applied somewhat uniformly throughout the season. With 10 inches of water the per cent of protein was higher when the water was applied in two irrigations than when three applications were made. Nevertheless, the more water that was applied in the first irrigation, the larger the per cent of protein. In the second series of experiments with 10 inches of water, practically the same results were obtained. Two irrigations gave a higher per cent of protein than did three; and when most of the water was applied in the first irrigation, the largest per cent of protein was invariably found. With 15 inches of water, two irrigations brought about the highest per cent of protein; when three applications were employed, it appeared immaterial how the water was distributed. With oats, grown under 15 inches of water, two irrigations gave a somewhat smaller per cent of protein than did three.

Summing up these data it seems that the composition of wheat is most responsive to the distribution of irrigation water when the amount is small. It appears invariably to be the rule, that when the greater part of the water is applied early in the season, the per cent of protein is the highest. The more irregular the applications are, the higher the per cent of protein appears to be. On the other hand, when the distribution is such that the per cent of moisture remains constant throughout the growing season the per cent of protein falls. When water is so applied that a high moisture period is followed by one of low moisture the per cent of protein increases. A more complete examination of the data on hand might lead to very far reaching results. The question of the effect of water distribution on crop composition offers, surely, another very alluring field of experimentation for those engaged in irrigation studies.

XIV. COOKING TESTS.

A number of vegetables, notably potatoes, carrots, onions and cabbage, grown with different quantities of irrigation water, were subjected to cooking tests. One set was distributed among a number of private families with instructions as to cooking and observations to be made. Another set was placed in the hands of a domestic science expert who carried on careful cooking tests with the material provided.

The work proved beyond doubt, that the quantity of water used in irrigation causes changes in the plant tissues, notwithstanding the great difficulty in securing fair samples for investigation, that are easily recognized after cooking. Such work should be encouraged and given far wider recognition, for it is one method whereby the superiority of irrigated crops may be demonstrated.

MILLING TESTS.[1]

The Chemical Department of the Utah Experiment Station has been conducting investigations during the past eight years regarding the milling, chemical and baking characteristics of different varieties of wheat grown under irrigated and dry-farming conditions. A great many varieties of wheat have been investigated, many of which were imported from different sections of the country. The dry-farming varieties of wheat have been grown on the several experimental dry farms, while the irrigated varieties have been grown on the irrigated farm located in the Cache Valley at Greenville.

In 1908 a preliminary report of these investigations was published.[2] Some very important results were obtained. It was found that the dry-farming wheats were characterized by a low moisture and a high protein content. The fact that dry-farming wheats have a low moisture content is important. A difference of one per cent in moisture in a large consignment of wheat renders the wheat having the lower moisture content of higher intrinsic value. It was found that the protein content of the flour produced from the durum varieties of wheat was 17.64 per cent. The protein content of the flour produced from the common bread varieties of wheat was found to be 16.79 per cent, while the protein content of the flour produced from irrigated wheat was found to be 13.34 per cent, thus clearly indicating the higher protein content of

1. Stewart and Hirst reprinted from the Journal of Industrial and Engineering Chemistry. Vol. 4, No. 4., April, 1912.
2. Stewart and Greaves. Bull. 103, Utah Experiment Station.

the flour from dry-farm wheats. It was found, however, that in many cases the millers were unable to produce good flour, from the baker's point of view, from the wheat they obtained from the farmers. These investigations showed that this was due to two causes: first, the most common variety of wheat grown in the State, the Gold Coin, contained the lowest protein content of any of the varieties of wheat tested; second, the farmers were not united on any one particular variety of wheat or any few varieties, but each farmer was governed in his choice of the variety by his own personal inclinations, irrespective of the quality of wheat grown. The work clearly demonstrated the necessity of uniting on one or two varieties of wheat to be grown by the farmers for bread-making purposes, and it also clearly demonstrated the necessity of uniting upon the variety of wheat having a high protein content, good chemical, milling and baking characteristics.

Since the publication of this bulletin, the work has been continued and the summarized results obtained by the three-year investigations, 1907-8-9, are given herewith.

The summarized results for the yield of milling products of spring and winter dry-farming and irrigated wheat during the years 1907-8-9 are recorded in Table XIV.

The weight per 100 kernels of the irrigated wheat is greater than that of either the spring or winter dry-farming wheat. The yield of flour, bran and shorts shows nothing characteristic for the wheats grown under different conditions.

The results obtained for the moisture content of the flour, wheat, shorts, and bran are brought together in Table XV.

The moisture content is low in every case. The moisture content of the irrigated wheat is higher than that of the dry-farm wheat. The moisture content of the bran is practically the same as that of the wheat. The moisture of the flour is about two per cent higher than that of the wheat, while that of the shorts is about one per cent higher than the wheat.

The results for the protein content of flour, wheat, shorts and bran are brought together in Table XVI.

It is thus seen that the lowest protein content is found in the irrigated wheat. This has been previously observed at

TABLE NO. 14.

SUMMARIZED RESULTS FOR YIELD OF MILLING PRODUCTS—RESULTS RECORDED AS PER CENT OF DRY WEIGHT.

	Tests	Weight 100 Kernels	Flour	Bran	Shorts	Error
Irrigated wheat, 25 in. water	10	4.008	68.08	23.39	8.52	—0.01
Irrigated wheat, 15 in. water	10	4.065	69.24	22.94	8.10	+0.28
No irrigation[1]	10	3.569	67.88	24.75	7.11	—0.26
Winter dry-farm wheat	136	3.004	69.21	22.45	8.31	—0.03
Spring dry-farm wheat	17	3.106	66.09	20.95	12.13	—0.83

TABLE NO. 15.

SUMMARIZED RESULTS FOR MOISTURE IN FLOUR, WHEAT, SHORTS AND BRAN.

	Tests	Flour	Wheat	Shorts	Bran
Irrigated wheat, 25 inches water	10	10.41	8.46	9.41	8.54
Irrigated wheat, 15 inches water	10	10.41	8.50	9.36	8.36
No irrigation	10	10.43	8.44	9.35	7.68
Winter dry-farm wheat	136	9.89	8.11	9.23	8.74
Spring dry-farm wheat	19	10.29	8.12	9.85	8.75

TABLE NO. 16.

SUMMARIZED RESULTS FOR PROTEIN IN FLOUR, WHEAT, SHORTS AND BRAN.

	Tests	Flour	Wheat	Shorts	Bran
Irrigated wheat, 25 inches water	10	12.63	14.00	16.40	18.87
Irrigated wheat, 15 inches water	10	12.92	14.35	16.89	18.66
No irrigation	10	13.62	15.45	17.67	19.32
Winter dry-farm wheat	136	14.64	15.76	18.27	20.87
Spring dry-farm wheat	19	15.74	16.85	19.17	20.39

1. Wheat grown on irrigated land but receiving no irrigation water during the growing season; used as a check on application of varying amounts.

this experiment station.[1] The result obtained for the same varieties of wheat grown on the same land but receiving no irrigation water clearly indicates that the decrease in protein is due to the influence of the water and not to differences in varieties grown on irrigated and dry-farming land. This difference is also observed in the flour, bran and shorts. It is manifest to a greater degree, however, in the flour when the yield is taken into consideration.

The difference in the amount of water applied to the plots receiving 25 inches and 15 inches of water is not sufficient to make any marked difference in the amount of protein in the wheat, flour, bran and shorts, although a slight difference is noticed. The difference between the protein content of wheat which had received 25 inches of irrigation water and the spring dry-farm wheat is 2.85, the difference in the protein content of the flour produced from these wheats 3.11, while that of the shorts and bran is 2.77 and 1.42 per cent, respectively.

The summarized results obtained for the chemical composition of the flour produced from spring, winter and irrigated grain are recorded in Table No. 17.

The flour produced from the winter dry-farm wheat has a slightly lower moisture content than the flour produced from the other kinds of wheat. The protein content of the flour produced from the wheat receiving the greatest amount of irrigation water is 3.11 per cent lower than that produced from spring dry-farm wheat and 2.01 per cent lower than that produced from dry-farm winter wheat. In case of the irrigated varieties of wheat, as the amount of water applied decreases, the protein content increases. The protein content of the flour produced from wheat which received no irrigation water is one per cent greater than that produced from wheat receiving an application of 25 inches, notwithstanding the fact that the seed wheat in both cases was the same and the non-irrigated wheat was grown on land which had been irrigated in previous years. The moist and dry-gluten content of the flour produced from the irrigated wheat is considerably lower than that produced from either spring or winter dry-farm wheat.

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1. Widtsoe, Bull. 80, Utah Experiment Station.

TABLE NO. 17.

SUMMARIZED RESULTS FOR CHEMICAL COMPOSITION OF FLOUR.

	Tests	Moisture	Protein	Moist Gluten	Dry Gluten	Ratio of Wet to Dry Gluten	Ash
Irrigated wheat, 25 in. water	10	10.41	12.63	34.05	11.72	2.73:1	0.578
Irrigated wheat, 15 in. water	10	10:41	12.92	32.55	11.63	2.79:1	0.544
No irrigation	10	10.43	13.62	35.18	12.58	2.79:1	0.552
Winter dry-farm	136	9.89	14.64	40.14	14.14	2.85:1	0.529
Spring dry-farm	18	10.29	15.74	44.12	15.32	2.86:1	0.689

TABLE NO. 18.

SUMMARIZED RESULTS FOR BREAD-MAKING VALUE.

	Tests	Cc of Water Added	Cc of Water Retained	Ratio of Protein to vol. of Water Added	Wt. of Loaf	Vol. of Loaf	Ratio of Protein to vol. of Loaf
Irrigated wheat, 25 in. water	10	204	104	1:16.4	474	1605	1:127.1
Irrigated wheat, 15 in. water	10	185	105	1:14.3	475	1630	1:126.2
No irrigation	10	204	109	1:15.1	479	1655	1:121.5
Winter dry-farm	108	195	104	1:13.3	474	1681	1:114.8
Spring dry-farm	11	227	124	1:14.4	494	1841	1:117.0

The summarized results for the bread-making value of the flour produced from spring, winter dry-farm grains and the irrigated grains are recorded in Table No. 18.

The ratio of protein to volume of water added is narrower in case of the dry-farm grains. The volume of loaf made from dry-farm flour is slightly greater than that made from irrigation flour. The ratio of protein to volume of loaf is narrower in the dry-farm flour than in the irrigated flour.

The investigations extending over a period of eight years clearly demonstrate the fact that the dry-farm grains in Utah are characterized by a low moisture content and a high protein content. They also clearly indicate that the protein content of the dry-farm wheats is higher than the protein content of the wheat on irrigated farms.

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